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The effect of 1.06 μm illumination on the photoluminescence of InAs/GaAs quantum dots

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Optical experiments with self-organised InAs/GaAs quantum dots (QD) show high quantum efficiency of photoluminescence (PL) which is important for laser applications [1]. However the channels of nonradiative carrier recombination which competes with PL in QDs are not understood yet. In the present contribution we study the effect of enhancement of PL quantum efficiency of InAs/GaAs QDs induced by subband 1.06 μm illumination.

Experiments were carried out on four samples (A, B, C, D) with InAs QDs grown by MBE on (311B) (samples A and C) or (100) (samples B and D) surface of semiinsulating GaAs substrate. Samples A and B consisted 10 layers of InAs QDs, C and D were samples with one QD layer. PL was excited by Ar-laser ($\lambda = 514$ nm) with power density $P_{\mathrm{Ar}} = 1-10\,\mathrm{W/cm^2}$ which is well below the saturation limit for ground electron and hole QD states in our samples. Experiments were carried out at $T = 77$ K. The PL spectral line was centred around 1.2 eV and had the spectral width of 40–80 meV depending on the sample. The PL spectrum was measured when the sample was excited by additional 1.06 μm illumination from cw or Q-switched YAG:Nd laser (power densities, P_{YAG}, up to 500 W/cm^2).

Figure 1 shows the photoluminescence spectra of sample A with (curves (a) and (b)) and without (curve (c)) additional 1.06 μm illumination of YAG:Nd laser. It is seen that PL intensity increases in the presence of 1.06 μm (1.17 eV) excitation which shows the enhancement of quantum efficiency of PL induced by subband illumination. In sample A the maximum relative increase (60%) was observed. The relative increase of the PL induced by 1.06 μm illumination is sublinear with the intensity of YAG laser and the enhancement effect reaches saturation for high power density, P_{YAG}.

The most interesting experimental result is that the relative increase of quantum efficiency depends on the wavelength of detected PL and the effect is stronger on the low-energy side of PL spectral line (see Fig. 1). This makes us to conclude that the effect of the quantum efficiency enhancement is governed by the processes directly connected with the properties of InAs QDs or InAs/GaAs interface but not with the GaAs buffer layer where carriers are initially created. Different wavelength of PL corresponds to QDs with different size. The wavelength of PL increases with the increase of the QD size. Apparently experimental results show that the relative increase of the quantum efficiency increases with the size of QD.

We explain the effect of the increase of QD quantum efficiency in terms of photoionisation of carrier traps which are playing a role of centres of nonradiative carrier recombination. Carriers created by interband (Ar-laser) excitation in GaAs are captured

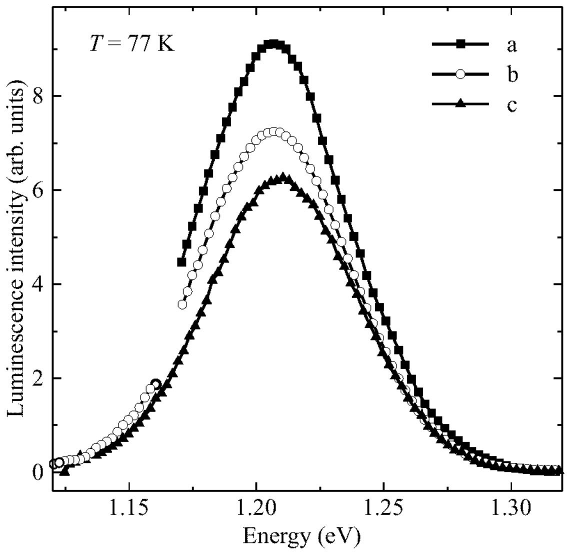

Fig 1. PL spectra of InAs/GaAs QDs measured at $P_{Ar} = 2.5\,W/cm^2$ and different power densities, P_{YAG}, of additional 1.06 μm illumination (W/cm^2): (a)—240; (b)—90; (c)—without 1.06 μm excitation.

to InAs QDs where they may recombine radiatively or captured by traps located at the InAs/GaAs interface. The competition between radiation and trap capture processes determines the quantum efficiency of PL. If the lifetime of carriers at the traps is long enough, then the subband 1.06 μm illumination will induce ionisation of carriers from the traps, thus giving additional chance for the carrier to participate in the radiative QD recombination resulting in PL. The value of relative increase of quantum efficiency depends on the ratio of the photoionisation rate and the lifetime of the carriers captured to traps. Thus the effect should be stronger for carriers which have a longer lifetime on the traps. The results of the experiments lead us to the assumption that carrier lifetime on the traps increases with the increase of QD size which may be due to the weaker overlap of electrons and holes participating in the nonradiative trap recombination in bigger QDs. This is reasonable if the nonradiative recombination occurs between the one carrier (e.g. electron) captured on the trap at the InAs/GaAs interface and another carrier (hole) located in the InAs QD.

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